global environmental solutions

Soil and Land Resource Assessment

Mandalong Mine

LW22 – LW23 Modification

Report Number 630.11810

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Centennial Mandalong Pty Limited

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Soil and Land Resource Assessment

Mandalong Mine

LW22 – LW23 Modification

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Table of Contents

Table of Contents

TABLES

Table of Contents

FIGURES

PLATES

APPENDICES

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1 INTRODUCTION

SLR Consulting (SLR) was engaged by Centennial Mandalong Pty Limited (Centennial Mandalong) to prepare a Land and Soil Resource Assessment for the proposed Mandalong Longwall Panel 22 to 23 (LW22 – LW23) Modification (the Project). This Land and Soil Resource Assessment will be used to support the modification to the existing development SSD-5144 which was granted on 12 October 2015 by the NSW Planning Assessment Commission under Part 4, Division 4.1 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

1.1 Project Overview

Mandalong Mine is an existing underground longwall coal mining operation producing thermal coal that is supplied to domestic and export markets. It is located approximately 35 kilometres south-west of Newcastle near Morisset in New South Wales. Mandalong Mine is 100 percent owned and operated by Centennial Mandalong Pty. Ltd (Centennial Mandalong), a subsidiary of Centennial Coal Company Ltd. Centennial Coal Company Limited is a wholly owned subsidiary of Banpu Public Company Ltd.

Mandalong Mine operates under Development Consent SSD-5144 which was granted on 12 October 2015 by the NSW Planning Assessment Commission under Part 4, Division 4.1 of the EP&A Act, and provided for extension of the mining area with a production limit of 6 million tonnes per annum of thermal coal from the West Wallarah and Wallarah-Great Northern Seams.

The currently approved Mandalong Mine comprises the underground workings and surface infrastructure of the following:

- The Mandalong Mine Access Site, encompassing underground workings and associated surface infrastructure near Morisset.

- Delivery of run-of-mine coal from the underground workings to the Cooranbong Entry Site. The Cooranbong Entry Site coal handling and processing facilities are approved under the Northern Coal Logistic Project (SSD-5145).

- Delivery of run-of-mine coal from the underground workings to the Delta Entry Site, located near Wyee at the Vales Point Rail Unloader Facility. The coal handling facility is approved under DA35-2-2004.

- Mandalong South Surface Site (MSSS), which is yet to be constructed, encompassing ventilation shafts, ventilation fans and underground delivery boreholes located approximately 6 kilometres south-west of the Mandalong Mine Access Site.

An igneous sill exists to the west of approved longwall panels 22 to 24 (LW22 – LW24). Due to historic uncertainty associated with the extent of the igneous sill, LW22 – LW24 were shortened as a conservative measure to mitigate the sill's impact on the mine's production. In recent times through ongoing geological exploration and the successful extraction of adjacent longwall panels below the igneous sill its extent and condition has become better understood. This has resulted in the proposed extension of LW22 – LW23 within the Study Area of SSD-5144.

Centennial Mandalong has prepared a Statement of Environmental Effects (SEE) to support an application seeking to modify Development Consent SSD-5144 under Part 4 of the EP&A Act. The modification is seeking to undertake the secondary extraction of LW22 – LW23 within the Study Area of SSD-5144 as illustrated on **Figure 1**.

Outlined below are the primary components of the Mandalong LW22 – LW23 Modification:

- Extension of LW22 from 1,630 m to 2,212 m. This yields 617,381 additional tonnes beyond 1,793,842 tonnes already approved.

- Extension of LW23 from 1,631 m to 2,392 m. This yields 799,933 additional tonnes beyond 1,799,425 tonnes already approved.

1.2 Legislative Framework

State Significant Development (SSD) Consent SSD-5144 was granted on 12 October 2015 by the NSW Planning Assessment Commission under Part 4 Division 4.1 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). Centennial Mandalong is now proposing to modify its Development Consent SSD 5144 for the Mandalong LW22 – LW23 Modification. SSD consents may be modified under Section 96 of the EP&A Act provided that the development as modified will be substantially the same development as the development for which consent was originally granted.

It is considered the proposed modifications to the Mandalong Southern Extension Project SSD-5144 development consent are substantially the same development as the development for which consent was originally granted being an underground longwall coal mine. The proposed modification will provide additional coal resources given the improved understanding regarding the extent and condition associated with the igneous sill. As such, it is considered the modification can be modified pursuant to Section 96(2) of the EP&A Act.

1.3 Study Area

The Study Area is shown on **Figure 1** which includes the limit of subsidence defined by the 26.5^0 angle of draw from the LW22 – LW23 voids. The proposed modification does not require any additional surface infrastructure. The Study Area encloses a total area of approximately 172 hectares, comprising both native vegetation and cleared grassland.

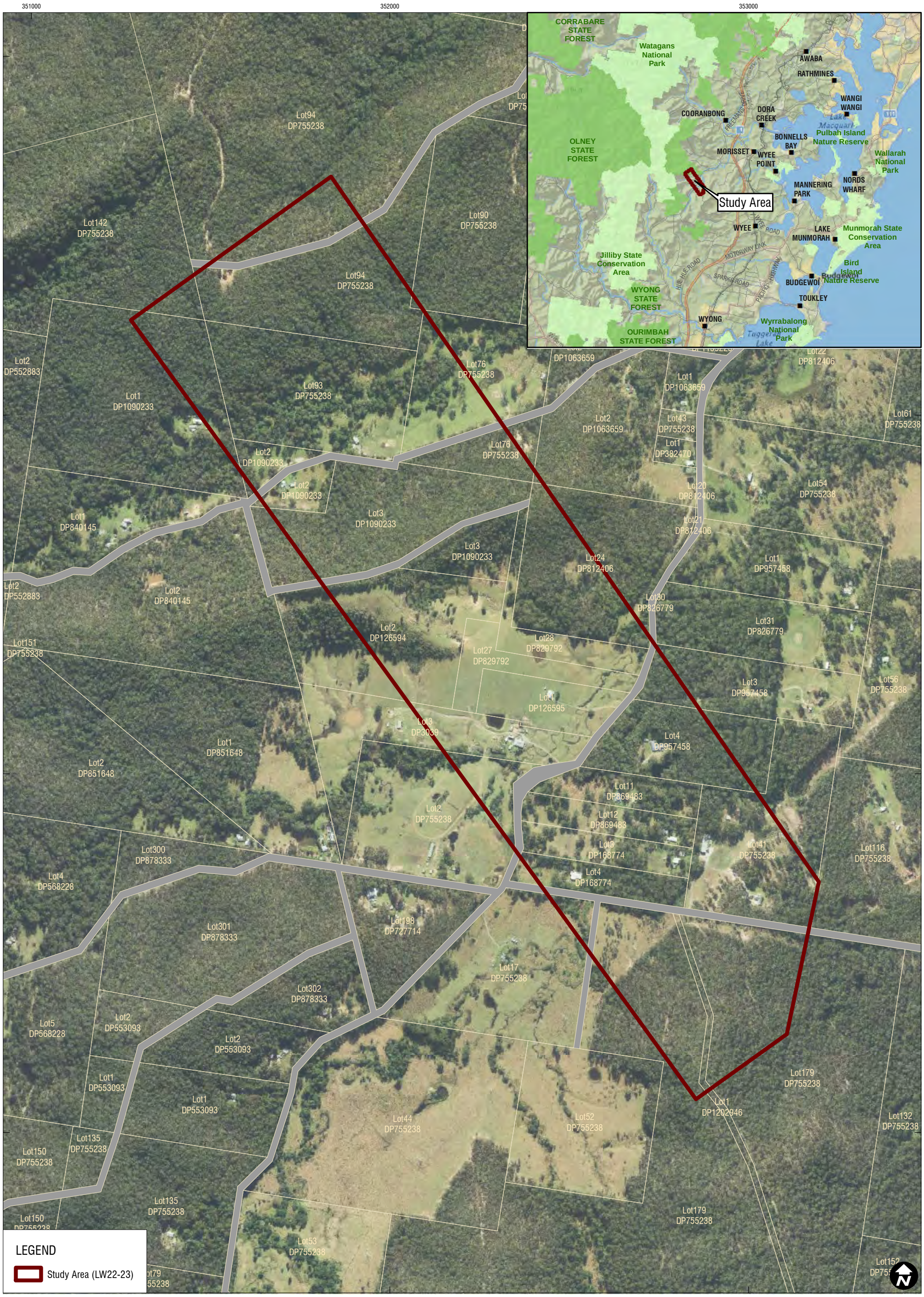
1.4 Assessment Objectives and Standards

The key objectives of the Soil and Land Resource Assessment undertaken by SLR are as follows:

Objective 1 Classify and determine the soil profile types within the Study Area using the *Australian Soil Classification* (ASC) system (Isbell, 1996), including a description and figure showing the distribution of each soil type.

Objective 2 Provide a description of, and figures showing, the land capability within the Study Area using *The Land and Soil Capability Assessment Scheme: Second Approximation* (Office of Environment and Heritage (OEH), 2013).

Objective 3 Provide recommendations to mitigate soil erosion and sedimentation associated with the works and soil stockpiles using *Managing Urban Stormwater: Soils and Construction Volume 1* (Landcom, 2004) and *Volume 2E Mines and Quarries* (Department of Environment and Climate Change, 2008).



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Study Area

FIGURE 1

2 EXISTING ENVIRONMENT

2.1 Climate

A continuous daily rainfall dataset was obtained as SILO Patched Point Data, which is based on historical data from a particular Bureau of Meteorology (BOM) station with missing data 'patched' in from interpolations from nearby stations. SILO data was obtained for the BOM Cooranbong (Avondale) Station (station number 61012) which is located approximately 10 kilometres to the north-east of the Study Area. Daily rainfall records from January 1889 to December 2014 were utilised. The average annual rainfall for the area was 1,123 millimetres, with a range from 531 millimetres to 1,994 millimetres.

The BOM classifies the Study Area as being located in a temperate climate zone with no designated wet season, although the area can be susceptible to occasional heavy showers and thunderstorms due to easterly troughs during warmer months. Summer winds are generally from the south or south-east, with a tendency for afternoon north-easterly winds. During winter, winds are predominantly from the south or south-west.

2.2 Geology

The Study Area is located in the south-western part of the Newcastle Coalfield, which occupies the north-eastern portion of the Sydney Basin. The coal seams found here are the Wallarah seam and the Great Northern seam, which together form the upper part of the Permian Newcastle Coal Measures.

Above the Wallarah and Great Northern Seams lies the Narrabeen Group, which are comprised of variable sequences of interbedded claystones, siltstones and fine to coarse-grained sandstones. The Munmorah Conglomerate is a sandstone-dominated formation within the Narrabeen Group, which typically occurs between 60 to 140 metres above the Newcastle Coal Measures.

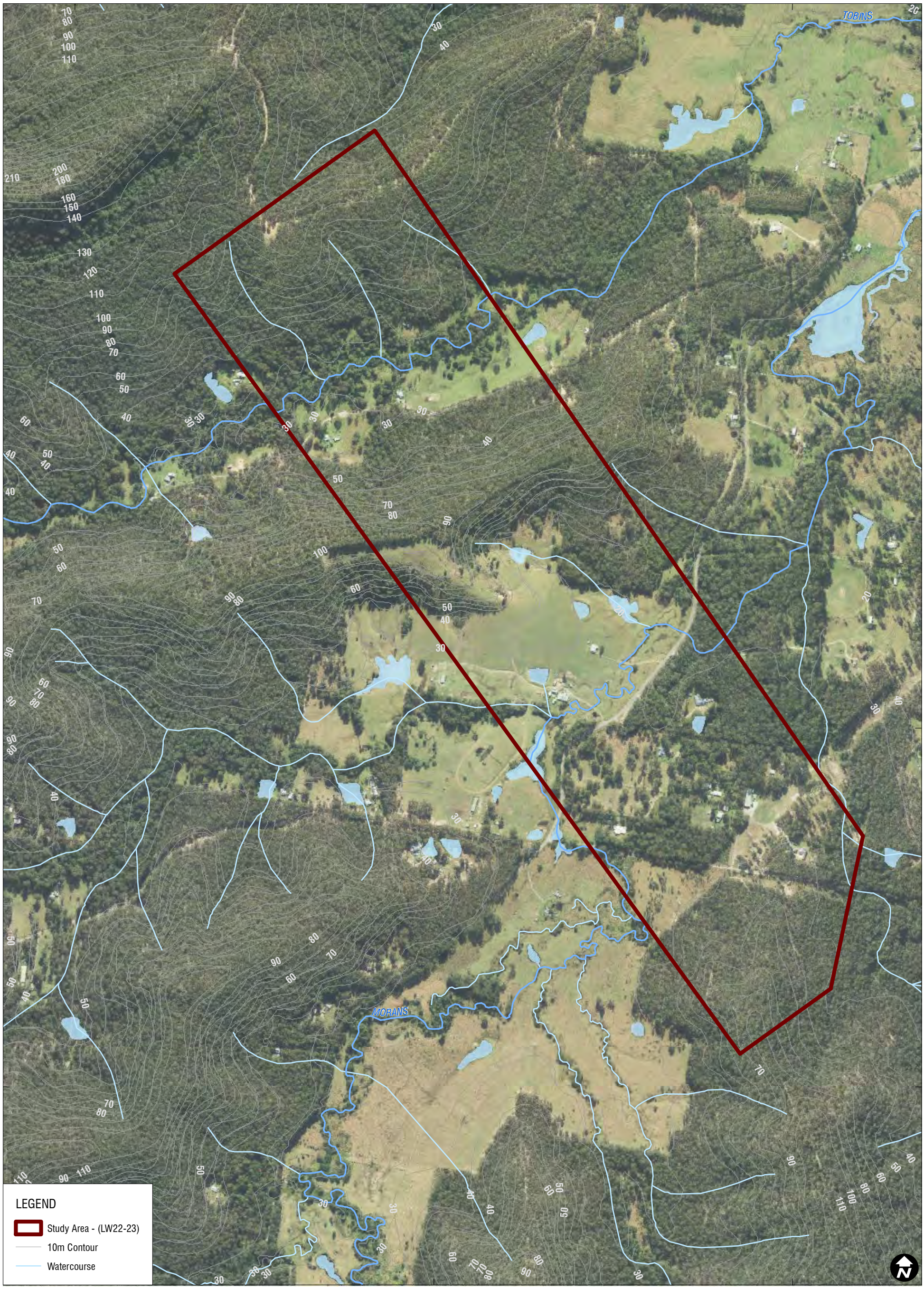
2.3 Topography and Hydrology

The Study Area is typified by relatively flat, low lying areas surrounded by densely timbered ridgelines. Elevations on these ridgelines reach up to 100 metres Australian Height Datum (AHD). The small areas of relatively flat land adjacent to these ridgelines has generally been cleared and is used for small scale rural production, as shown in **Figure 2**. The flats are relatively low lying with surface elevations generally less than 25 metres AHD. The slope analysis (**Figure 3**) further highlights the low lying flats, in green, which have been cleared for grazing.

The Study Area is located in the upper reaches of the Mandalong Valley Floodplain and has four main drainage channels flowing through it (**Figure 2**) which form part of the Lake Macquarie catchment. In addition to these drainage channels there a numerous small farm dams which have been constructed both as flood mitigation measures and stock water sources.

All drainage channels within the Study Area are considered intermittent watercourses with limited or zero flow during low rainfall periods suggesting that the number of users dependent on flows from these watercourses, would be limited.

The *Water Management Plan* (GHD, 2016) found the groundwater sources associated with the Study Area are generally low yielding and predominantly weathered and/or fractured sandstone, coal seams and some clayey quaternary alluvium.



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Topography and Hydrology

FIGURE 2

351000

352000

353000

6334000

6333000

6332000

6331000

LEGEND

Study Area (LW22-23)

SlopeCode

< 3%

3 - 5%

5 - 10%

10 - 18%

18 - 32%

32 - 50%

> 50%

0 100 200 300 400 m

Scale: 1:10,000

GDA 1994 MGA Zone 56

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Slope Analysis

FIGURE 3

2.4 Vegetation and Land Use

Assessment of recent aerial images shows that the majority of the Study Area remains under native vegetation (approximately 74%), as seen on **Figure 2**. The remainder is land that has been previously cleared and may be suitable for agricultural enterprises. A site inspection in June 2016 by SLR's Senior Agronomist, in conjunction with a desktop assessment, has shown that small scale cattle and horse grazing of native grass species such as kangaroo grass (*Themeda australis*), Poa tussock (*Poa labillardierei*) and red grass (*Bothriochloa* spp.) is the dominant agricultural enterprise. In addition, there are isolated areas where cattle graze improved pasture, with the pasture dominated by kikuyu grass (*Pennisetum clandestinum*). No intensive cropping activities were observed at the time of the assessment.

Grazing within the Study Area appears to be used as a grass and vegetation management tool rather than an income generating agricultural enterprise. Overall farm size is considered small and many would be classified as hobby farms with a very low potential to produce significant agricultural income. Approximately 44 hectares of potential grazing land is currently available for agricultural use.

The Study Area includes a small portion of the Olney State Forest in the north-east.

Plate 1 Cattle grazing grass pasture on a cleared flat in the Study Area

Plate 2 Eucalypt wooded area on a steep slope within the Study Area

Plate 3 Eucalypt wooded area on a plateau the Study Area

2.5 Soil Landscape Units

Soil Landscapes Units are described as "*areas of land that have recognisable and specific topographies and soils that can be presented on maps and described by concise statements"*.

The Soil Landscape Units within the Study Area have been mapped by the former NSW Department of Land and Water Conservation, incorporating the NSW Soil Conservation Service (now part of NSW Department of Primary Industries (DPI)), on the *Soil Landscapes of the Gosford – Lake Macquarie Sheet 1:100 000 Sheet* (Murphy, 1993) shown in **Figure 4**. Four soil landscapes occur in the Study Area and are summarised in **Table 1**.

Below is a summary of the key agricultural features of each Soil Landscape Unit:

- The majority of the Study Area (68%) is highly to severely constrained for cultivation (cropping) enterprises.
- The Mandalong Soil Landscape Unit is highly to severely constrained for any agricultural enterprises, which covers 40% of the Study Area.
- Agricultural land best suited to grazing enterprises includes the Gorokan, Yarramalong and Wyong Soil Landscape Units, which covers 60% of the Study Area.
- Agricultural land suited to both cultivation and grazing enterprises is associated with the Yarramalong and Wyong Soil Landscape Units, which covers 32% of the Study Area. It should be noted that localised areas within Yarramalong and Wyong Soil Landscape Units have high to severe limitations for cultivation due to waterlogging.

Table 1 Soil Landscape Units

Soil Landscape	**Study Area**		**Agricultural Limitation Rating**	
Unit	**Hectares**	**%**	**Grazing**	**Cultivation**
Mandalong	68	40	High – Severe	High – Severe
Gorokan	49	28	Low	High – Severe
Yarramalong	49	28	Low	Low (High – Severe*)
Wyong	6	4	Low – Moderate	Low (High – Severe*)
Total	**172**	**100**	**for localised waterlogged and floodplain areas*	

Full descriptions of each Soil Landscape Unit mapped within the Study Area follow **Figure 4**.

351000
352000
353000
6334000
6333000
6332000
6331000

LEGEND

Study Area (LW22-23)

Soil Landscapes

GOROKAN

MANDALONG

WYONG

YARRAMALONG

0 100 200 300 400 m

Scale: 1:10,000
GDA 1994 MGA Zone 56

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Soil Landscape Units

FIGURE 4

2.5.1 Mandalong Soil Landscape Unit

The Mandalong Soil Landscape Unit consists of rolling to steep low hills on Patonga Claystone in the Watagan Mountains. The landscape has local relief to 120 metres and slope gradients of between 20 and 60%. The landscape is characterised by narrow crests and ridges, short steep slopes and narrowly spaced drainage lines. The land is regenerating tall open-forest (**Plate 4**). The soils are dominated by moderately to deep Red, Brown and Yellow Podzolics Soils (Kurosols, Chromosols and Sodosols) on claystone, shallow to moderately deep Yellow Podzolic Soils (Kurosols, Chromosols and Sodosols) on sandstone or rock outcrops along drainage lines.

The limitations of this unit include mass movement hazards, steep slopes, erosion hazards and foundation hazards. Soils have low wet bearing strength, can be acidic, sodic and have low fertility. The land capability is deemed to have generally high to severe limitations to both cropping and grazing.

This soil landscape occurs across 68 hectares (40%) of the Study Area.

Plate 4 Mandalong Soil Landscape

2.5.2 Gorokan Soil Landscape Unit

The Gorokan Soil Landscape Unit consists of undulating low hills and rises on lithic sandstones of the Tuggerah Formation. Local relief is less than 30 metres, with slope gradients less than 15%. The landscape is characterised by broad crests and ridges, long gently inclined slopes and broad drainage lines. The land is partially cleared low open-forest (**Plate 5**). The soils are dominated by moderately deep Soloths (Sodosols), Yellow Podzolic Soils (Kurosols, Chromosols) on ridges and crests, Yellow and Grey-Brown Podzolic Soils (Kurosols, Chromosols) on slopes and Gleyed Podzolic Soils (Hydrosols) along drainage lines.

Limitations to this unit include very high erosion hazard, foundation hazard (localised), seasonal waterlogging, hardsetting, strongly acidic, low fertility, plastic and impermeable soils. The land capability is deemed to have generally high to severe limitations for regular cultivation, however low limitations for grazing.

This soil landscape occurs across 49 hectares (28%) of the Study Area.

Plate 5 Gorokan Soil Landscape

2.5.3 Yarramalong Soil Landscape Unit

The Yarramalong Soil Landscape Unit consists of floodplains on Quaternary alluvium with level to gently undulating narrow to moderately broad dissected alluvial plains. Slope gradients are less than 3% and local relief is less than 10 metres (**Plate 6**). This unit includes meander scrolls, terraces, oxbows and backswamps. The soils are generally dominated by Alluvial Soils and Siliceous Sands (Rudosols) in upper reaches, deep Alluvial Soils (Rudosols) and Red Earths (Kandosols) along levee banks as well as deep Yellow and Brown Podzolic Soils (Kurosols, Chromosols, Sodosols) along the backplain and Yellow Earths (Kandosols) on some terraces.

Limitations to this unit include flooding, foundation hazards, seasonal waterlogging, stream bank erosion and low fertility. The land capability is deemed to have generally low limitations for cultivation and grazing. Localised areas of heavier soils on the poorer drained country in the lower tract floodplain have high to severe limitations.

This soil landscape occurs across 49 hectares (28%) of the Study Area.

Plate 6 Yarramalong Soil Landscape

2.5.4 Wyong Soil Landscape Unit

The Wyong Soil Landscape Unit consists of broad, poorly drained deltaic floodplains and alluvial flats of Quaternary sediments on the Central Coast Lowlands (**Plate 7**). Slope gradients are less than 3%, and local relief is less than 10 metres. Meander scrolls, oxbows and swamps are common in this landscape. The land is extensively cleared open-forest. The soils are dominated by deep Yellow and Brown Podzolic Soils (Kurosols, Chromosols), Soloths (Sodosols), with some Humus Podozols (Podosols) around lake edges.

Limitations to this unit include flooding, seasonal waterlogging, foundation hazard, permanent waterlogging (localised), stream bank erosion (localised), acid sulphate potential (localised), strongly acidic, poorly drained and impermeable soils of low fertility with saline subsoils. The land capability is deemed to have generally low limitations for cultivation except for water logged areas which have high to severe limitations. Generally, there are low to moderate limitations for grazing.

This soil landscape occurs across approximately 6 hectares (4%) of the Study Area.

Plate 7 Wyong Soil Landscape

3 SOIL SURVEY AND ASSESSMENT

3.1 Soil Survey Methodology

A field survey and a desktop study were undertaken to assess the distribution of soil resources within the Study Area This process consisted of the components outlined in the below sub-sections:

3.1.1 Reference Mapping

An initial soil map (reference map) was developed using the following resources and techniques:

- *Satellite imagery and topographic maps* - aerial imagery and topographic map interpretation was used as a remote sensing technique allowing detailed analysis of the landscape and mapping of features expected to be related to the distribution of soils within the Study Area. Aerial photographs and topographical maps were provided by Centennial Mandalong.
- *Reference information* - source materials were used to obtain correlations between pattern indicators and soil properties that may be observable in the field. These materials included cadastral data, geological, vegetation and water resources studies.
- *Previous soils information* - previous studies were taken into consideration for soils mapping and land assessment. These include the following:
    - *Soil Landscapes of Gosford – Lake Macquarie 1:100,000 Sheet* (Murphy, 1993);
    - Land Capability Spatial Data (Department of Natural Resources, 2005); and
    - *Soil and Land Resource Assessment Mandalong Southern Extension Project* (GSSE, 2013). This assessment conducted by GSSE (now SLR) is located to the south of the Study Area.
    - *Biophysical Strategic Agricultural Land Assessment Mandalong Transmission Line TL24 Relocation Project* (SLR, 2015) which is adjacent to the southern boundary of the Study Area.

3.1.2 Field Survey

Scale

Survey observations were undertaken to comply with the 1:100,000 scale survey criteria prescribed in the *Guidelines for Surveying Soil and Land Resources* (NCST, 2008). The recommended observation density for 1:100,000 scale survey is one observation every 100 hectares. For the Study Area of 172 hectares this equates to a total of two detailed observations.

The actual number of observations undertaken for the Study Area was thirteen detailed laboratory assessed profile descriptions described in **Section 3.3**, which equates to an approximate survey scale of 1:15,000.

Land access was unavailable for properties in the centre of the Soil and Land Resource Assessment Area which comprised properties: Lot 2 DP126594, Lot 27 DP829792, Lot 28 DP828792, Lot 3 DP3039, Lot 1 DP 126595 and Lot 2 DP755238 (**Figure 1**).

Survey Type

The field survey undertaken was an integrated and qualitative survey. An integrated survey assumes that many land characteristics are interdependent and tend to occur in correlated sets (NCST, 2008). Background reference information derived from sources cited in **Section 3.1.1** were used to predict the distribution of soil attributes in the field. The characteristics were evaluated to generate the correlated sets, including vegetation type, landform and geology.

Detailed Soil Profile Observation

Soil profiles were assessed in accordance with the *Australian Soil and Land Survey Field Handbook* (NCST 2009). Information was recorded for the major parameters specified in **Table 2** with samples taken from thirteen profiles for laboratory analysis.

Global Positioning System (GPS) readings were taken for all sites where detailed soil descriptions were recorded. Vegetation type and land use were also recorded. Soil exposures from cores were photographed during field operations, with photographs being a useful adjunct to description of land attributes.

Table 2 Field Assessment Parameters

Descriptor	Application
Horizon Depth	Weathering characteristics, soil development
Field Colour	Permeability, susceptibility to dispersion /erosion
Field Texture Grade	Erodibility, hydraulic conductivity, moisture retention, root penetration
Boundary Distinctness and Shape	Erosional / dispositional status, textural grade
Consistence Force	Structural stability, dispersion, ped formation
Structure Pedality Grade	Soil structure, root penetration, permeability, aeration
Soil Structure (Ped) & Size	Soil structure, root penetration, permeability, aeration
Stones – Amount & Size	Water holding capacity, weathering status, erosional / depositional character
Roots – Amount & Size	Effective rooting depth, vegetative sustainability
Ants, Termites, Worms etc.	Biological mixing depth

Soil layers at each profile site were also assessed according to a procedure devised by Elliot and Reynolds (2007) for the recognition of suitable topdressing material in the event surface disturbance occurs in the future. This procedure assesses soils based on grading, texture, structure, consistence, mottling and root presence.

3.1.3 Soil Laboratory Assessment

Soil samples from thirteen of the soil assessment sites were utilised in the laboratory testing program. Samples were analysed in order to:

- Classify soil taxonomic classes;
- Determine Land and Soil Capability and Agricultural Suitability classes; and
- Determine suitability of soil as topdressing material in future rehabilitation works.

Soil was collected from each major soil horizon (soil layer) and sent to the Scone Research Centre for analysis. Certificate of Analyses for these results are contained in **Appendix B**. The selected physical and chemical laboratory analysis parameters and their relevant application are listed in **Table 3**.

Table 3 Laboratory Analysis Parameters

Property	Application
Coarse fragments (>2mm)	Soil workability; root development
Particle-size distribution (<2mm)	Determine fraction of Clay (Cl), Silty (Si), Fine Sand (Fs) and Coarse Sand (Cs); Nutrient retention; exchange properties; erodibility; workability; permeability; sealing; drainage; interpretation of most other physical and chemical properties and soil qualities
Soil reaction (pH)	Nutrient availability; nutrient fixation; toxicities (especially aluminium (Al) and manganese (Mn)); liming; sodicity; correlation with other physical, chemical and biological properties
Electrical conductivity (EC)	Appraisal of salinity hazard in soil substrates or groundwater; total soluble salts
Cation Exchange Capacity (CEC) and exchangeable cations	Nutrient status; calculation of exchangeable cations including Sodium (Na), Calcium (Ca), Magnesium (Mg), Potassium (K) and exchangeable sodium percentage (ESP); assessment of other physical and chemical properties, especially dispersivity, shrink – swell, water movement, aeration
Munsell Colour Chart (Munsell)^	Drainage, oxidation, fertility, correlation with other physical, chemical and biological properties

Laboratory colour has been used except when mottling was 20% or greater indicated by ^, as field colour more accurately assesses primary colour and dominant mottle colour.

The laboratory methods used by Scone Research Centre for key physical and chemical parameters are provided below in **Table 4.**

Table 4 Laboratory Test Methods

Parameter	Method
Particle Size Analysis (PSA)	Sieve and hydrometer
pH	1:5 soil/water extract
EC	1:5 soil/water extract
CEC and exchangeable cations	(AgTU)+ extraction

3.1.4 Soil Type Nomenclature

The applicable technical standard adopted by SLR for the Project is the ASC system. This is the standard nomenclature routinely used as the soil classification system in Australia.

3.2 Soil Survey Results

The dominant soil types within the Study Area were ground-truthed by SLR at the scale of approximately 1:15,000 and determined using the Australian Soil Classification (ASC) System (Isbell, 1996). This assessment consists of 12 detailed laboratory assessed soil profiles. The main assessment points are listed below.

- Three major soil orders are present in the Study Area, Kurosols, Sodosols and Dermosols (**Table 5**)

- Kurosols are soils with a strong texture contrast between the A horizon and strongly acidic B horizons. Many Kurosols have unusual subsoil chemical attributes such as high magnesium, sodium and aluminium. The Brown Kurosol comprises 5% of the Study Area

- Sodosols are soils that have a strong texture contrast between the topsoil and subsoil horizons and contain sodic subsoil. The Brown Sodosol comprises 72% of the Study Area.

- Dermosols are soils with structured B2 horizons and lacking strong texture contrast between the A and B horizons. The Brown Dermosol comprises 23% of the Study Area.

- Kurosols range from moderately low to moderate inherent fertility, depending on ASC Great Group classification, with both Mesotrophic Kurosols (moderate) and Magnesic (moderately low) occurring in the Study Area. The Dermosol is classed as having moderately high inherent fertility whilst the Sodosol has moderately low inherent fertility (Office of Environment & Heritage (OEH), 2012).

Table 5 Dominant Soil Types and Inherent Fertility

Australian Soil Classification	Inherent Fertility	Hectares	%
Brown Kurosol	Moderately Low - Moderate	9	5
Brown Sodosol	Moderately Low	124	72
Brown Dermosol	Moderately High	39	23
	Total	**172**	**100**

One representative site and soil profile description for the Kurosol, Sodosol and Dermosol follow **Figure 5**. All twelve sites and full soil profile descriptions are presented in **Appendix A**.

351000
352000
353000
6334000
6333000
6332000
6331000

M2
M1
3
2
M3
7
6
1
M7
8
9
M6

LEGEND

October Field Points
June Field Points
Study Area (LW22-23)

Soil Types

Dermosol
Sodosol
Kurosol

0 100 200 300 400 m

Scale: 1:10,000
GDA 1994 MGA Zone 56

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Soil Units

FIGURE 5

3.3 Soil Unit 1: Brown Kurosol

Soil Unit 1 is a Brown Kurosol. Kurosols are soils with a strong texture contrast between the A horizon and strongly acidic B horizons. Many Kurosols have unusual subsoil chemical attributes such as high magnesium, sodium and aluminium. Three representative sites for Soil Unit 1 are described below.

Table 6 Summary: Magnesic-Natric Brown Kurosol (Site 1)

Overview	
	
Landscape Site 1	
ASC Name	Magnesic-Natric Brown Kurosol
Representative Site	Site 1
Survey Type	Detail
Dominant Topography	Lower Slope
Dominant Land Use	Native Vegetation
Vegetation	Melaleuca, Stringybark, Blady Grass
Inherent Soil Fertility	Moderately Low
Slope	3%
Verified	Non-BSAL

Table 7 Profile: Magnesic-Natric Brown Kurosol (Site 1)

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.10	Dark greyish-brown (10YR 4/2) silty loam, weakly structured 5-15 mm blocky peds with weak consistence and a rough fabric. Nil mottling, nil stone content, abundant fine roots. Well drained with a gradual and even boundary. Sampled 0.0 – 0.10
	A2 0.10 – 0.25	Brown (7.5YR 4/3) bleached silty loam, weakly structured 10-20 mm blocky peds with weak consistence and a rough fabric. Nil mottling, nil stone content, abundant fine roots. Well drained with an abrupt and even boundary. Sampled 0.15 – 0.25
	B21 0.25 – 0.75	Yellowish brown (10YR 5/4^) silty clay, moderately structured 20-40 mm subangular blocky peds with moderate consistence and a rough fabric. 20% distinct orange mottles; nil stone content; coarse roots common. Poorly drained with a gradual and even boundary. Sampled 0.40 – 0.50
	B22 +0.75	Yellowish brown (10YR 5/4^) silty clay loam, moderately structured 30-50 mm subangular blocky peds with moderate consistence and a rough fabric. 40% distinct grey mottles, <5% gravel 5-15 mm, few coarse roots. Poorly drained with layer continuing beyond sampling depth. Sampled 0.65 – 0.75

Table 8 Chemical Parameters: Magnesic-Natric Brown Kurosol (Site 1)

Layer	pH (water)		ESP		ECe (1:5)		Ca:Mg	
	Unit	rating	%	rating	dS/m	rating	ratio	rating
A1	5.8	Moderately Acidic	4.4	Non-sodic	0.3	Non-saline	1.57	Low
A2	5.9	Moderately Acidic	7.0	Marginally Sodic	0.1	Non-saline	0.12	Low
B21	5.3	Strongly Acidic	7.7	Marginally Sodic	0.7	Non-saline	0.01	Very Low
B22	4.8	Strongly Acidic	7.4	Marginally Sodic	0.9	Non-saline	0.02	Very Low

3.4 Soil Unit 2: Brown Sodosol

Soil Unit 2 is a Brown Sodosol. Sodosols are soils with a strong texture contrast between the A horizon and a sodic B horizon which is not strongly acidic. The strongly sodic nature of the B horizon in these Sodosols leave them prone to dispersion and tunnel erosion if left exposed for prolonged periods to water movement or rainfall. One representative site for Soil Unit 2 is described below. The six soil profiles from Soil Unit 2 are described and shown in **Appendix A**.

Table 9 Summary: Subnatric Brown Sodosol (Site 2)

Overview	
	
Landscape Site 2	
ASC Name	Subnatric Brown Sodosol
Representative Site	Site 2
Survey Type	Detail
Dominant Topography	Creek Flat
Dominant Land Use	Horse Grazing
Vegetation	Spotted Gum, Kikuyu
Inherent Soil Fertility	Moderately Low
Slope	9%
Verified	Non-BSAL

Table 10 Profile: Subnatric Brown Sodosol (Site 2)

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.25	Greyish-brown (10YR 5/2) loamy sand, weakly structured 5-15 mm blocky peds with weak consistence and a rough fabric. Nil mottling, nil stone content, abundant fine roots. Well drained with a gradual and even boundary. Sampled 0.0 – 0.10
	A2 0.25 – 0.45	Brown (10YR 6/2) bleached loamy sand, weakly structured 5-10 mm blocky peds with weak consistence and a rough fabric. Nil mottling, nil stone content, abundant fine roots. Well drained with a clear and even boundary. Sampled 0.30 – 0.40
	B21 0.45 – 0.60	Yellowish brown (10YR 5/4^) clay loam, moderately structured 20-30 mm subangular blocky peds with moderate consistence and a rough fabric. 20% distinct yellow mottles; nil stone content; coarse roots common. Poorly drained with a gradual and even boundary. Sampled 0.40 – 0.50
	B22 0.60 – 0.80	Yellowish brown (10YR 5/4^) clay loam, moderately structured 30-50 mm subangular blocky peds with moderate consistence and a rough fabric. 30% distinct orange mottles, nil stone content, few coarse roots. Poorly drained with clear and even boundary. Sampled 0.65 – 0.75
	BC +0.80	Weathered parent material. Not sampled

Table 11 Chemical Parameters: Subnatric Brown Sodosol (Site 2)

Layer	pH (water)		ESP		ECe (1:5)		Ca:Mg	
	Unit	rating	%	rating	dS/m	rating	ratio	rating
A1	6.0	Moderately Acidic	1.2	Non-sodic	0.5	Non-saline	7.25	High
A2	6.6	Neutral	3.5	Non-sodic	0.2	Non-saline	4.07	Balanced
B21	6.3	Slightly Acidic	7.8	Marginally Sodic	0.3	Non-saline	0.94	Low
B22	5.9	Moderately Acidic	11.5	Strongly Sodic	0.6	Non-saline	0.39	Low

3.5 Soil Unit 3: Brown Dermosol

Soil Type 3 is a Brown Dermosol. Dermosols are soils with structured B2 horizons and lacking strong texture contrast between the A and B horizons. The sodic nature of the B horizon in the majority of these Dermosols leave them prone to dispersion and tunnel erosion if left exposed for prolonged periods to water movement or rainfall. One representative site for Soil Unit 3 is described below. The three soil profiles from Soil Unit 3 are described and shown in **Appendix A**.

Table 12 Summary: Eutrophic Brown Dermosol (Site 3)

Overview	
	
Landscape Site 3	
ASC Name	Eutrophic Brown Dermosol
Representative Site	Site 3
Survey Type	Detail
Dominant Topography	Mid Slope
Dominant Land Use	Horse Grazing
Vegetation	Spotted Gum, Kikuyu
Inherent Soil Fertility	Moderately High
Slope	6%
Verified	Non-BSAL

Table 13 Profile: Eutrophic Brown Dermosol (Site 3)

Profile	Horizon / Depth (m)	Description
	A1 0.0 – 0.10	Brown (10YR 5/3) loamy sand, weakly structured 5-15 mm blocky peds with weak consistence and a rough fabric. Nil mottling, nil stone content, abundant fine roots. Well drained with a gradual and even boundary. Sampled 0.0 – 0.10
	A2 0.10 – 0.35	Pale brown (10YR 6/3) loam, moderately structured 10-20 mm blocky peds with weak consistence and a rough fabric. Nil mottling, nil stone content, abundant fine roots. Well drained with a gradual and even boundary. Sampled 0.20 – 0.30
	B21 0.35 – 0.60	Yellowish brown (10YR 5/4^) loam, moderately structured 20-30 mm blocky peds with weak consistence and a rough fabric. 30% distinct yellow mottles; <5% gravel 5-15 mm; coarse roots common. Poorly drained with a gradual and even boundary. Sampled 0.40 – 0.50
	B22 +0.60	Yellowish brown (10YR 5/8^) loam, moderately structured 20-40 mm blocky peds with moderate consistence and a rough fabric. 40% distinct grey mottles, <5% gravel 5-15 mm, few coarse roots. Poorly drained with layer continuing beyond sampling depth. Sampled 0.65 – 0.75

Table 14 Chemical Parameters: Eutrophic Brown Dermosol (Site 3)

Layer	pH (water)		ESP		ECe (1:5)		Ca:Mg	
	Unit	rating	%	rating	dS/m	rating	ratio	rating
A1	5.9	Moderately Acidic	1.6	Non-sodic	1.2	Non-saline	2.38	Low
A2	5.5	Strongly Acidic	2.2	Non-sodic	0.3	Non-saline	1.00	Low
B21	5.6	Moderately Acidic	4.9	Non-sodic	0.2	Non-saline	0.19	Low
B22	5.7	Moderately Acidic	16.4	Strongly Sodic	0.7	Non-saline	0.02	Very Low

4 LAND AND SOIL CAPABILITY

4.1 Land and Soil Capability Methodology

The LSC classification applied to the Study Area was in accordance with the OEH guideline *The Land and Soil Capability Assessment Scheme; Second approximation* (OEH, 2013) (referred to as the LSC Guideline). This scheme uses the biophysical features of the land and soil to derive detailed rating tables for a range of land and soil hazards. The scheme consists of eight classes, which classify the land based on the severity of long-term limitations. The LSC classes are described in **Table 15** and their definition has been based on two considerations:

- The biophysical features of the land to derive the LSC classes associated with various hazards.
- The management of the hazards including the level of inputs, expertise and investment required to manage the land sustainably.

Table 15 Land and Soil Capability Classification

Class	Land and Soil Capability
Land capable of a wide variety of land uses (cropping, grazing, horticulture, forestry, nature conservation)	
1	**Extremely high capability land**: Land has no limitations. No special land management practices required. Land capable of all rural land uses and land management practices.
2	**Very high capability land**: Land has slight limitations. These can be managed by readily available, easily implemented management practices. Land is capable of most land uses and land management practices, including intensive cropping with cultivation.
3	**High capability land**: Land has moderate limitations and is capable of sustaining high-impact land uses, such as cropping with cultivation, using more intensive, readily available and widely accepted management practices. However, careful management of limitations is required for cropping and intensive grazing to avoid land and environmental degradation.
Land capable of a variety of land uses (cropping with restricted cultivation, pasture cropping, grazing, some horticulture, forestry, nature conservation)	
4	**Moderate capability land**: Land has moderate to high limitations for high-impact land uses. Will restrict land management options for regular high-impact land uses such as cropping, high-intensity grazing and horticulture. These limitations can only be managed by specialised management practices with a high level of knowledge, expertise, inputs, investment and technology.
5	**Moderate–low capability land**: Land has high limitations for high-impact land uses. Will largely restrict land use to grazing, some horticulture (orchards), forestry and nature conservation. The limitations need to be carefully managed to prevent long-term degradation.
Land capable for a limited set of land uses (grazing, forestry and nature conservation, some horticulture)	
6	**Low capability land**: Land has very high limitations for high-impact land uses. Land use restricted to low-impact land uses such as grazing, forestry and nature conservation. Careful management of limitations is required to prevent severe land and environmental degradation.
Land generally incapable of agricultural land use (selective forestry and nature conservation)	
7	**Very low capability land**: Land has severe limitations that restrict most land uses and generally cannot be overcome. On-site and off-site impacts of land management practices can be extremely severe if limitations not managed. There should be minimal disturbance of native vegetation.
8	**Extremely low capability land**: Limitations are so severe that the land is incapable of sustaining any land use apart from nature conservation. There should be no disturbance of native vegetation.

4.1.1 Calculating LSC Classes

The biophysical features of the land that are associated with various hazards are broadly soil, climate and landform and more specifically: slope, landform position, acidity, salinity, drainage, rockiness; and climate.

The eight hazards associated with these biophysical features that are assessed by the scheme are:

1. Water erosion
2. Wind erosion
3. Soil structure decline
4. Soil acidification
5. Salinity
6. Water logging
7. Shallow soils and rockiness
8. Mass movement

Each hazard is assessed against set criteria tables, as described in the LSC Guideline; each hazard for the land is ranked from 1 through to 8 with the overall ranking of the land determined by its most significant limitation.

Hazard 1: Water Erosion

The Study Area lies within the Eastern and Central NSW Division, and the appropriate criteria for this division were used in the assessment. Assessment of water erosion hazard is almost solely dependent on the slope percentage of the land, based on each Soil Landscape Unit. The only exception is land which falls within the slope range of 10 to 20%, which may be designated LSC Class 4 or LSC Class 5 depending on the presence of gully erosion and/or sodic/dispersible soils.

Hazard 2: Wind Erosion

There are four factors used to assess wind erosion hazard for each soil type. Three criteria were assessed to be consistent for each soil type:

- Average rainfall determines the capacity of the land to maintain vegetative cover and keep soil wet. The average rainfall for the region is 1,123 mm (BOM, 2015), and therefore the Study Area lies within the “greater than 500 mm rainfall” category for the purpose of assessing wind erosion hazard.

- Wind erosive power for the Study Area has been mapped as “Moderate” (NSW Department of Trade and Investment);

- Exposure of the land to wind was also determined to be “Moderate” throughout the Study Area; and

The determining factor with regard to wind erosion hazard was therefore the erodibility of each soil type as determined by soil texture according the LSC Guideline.

Hazard 3: Soil Structure Decline

Soil structure decline is assessed on soil characteristics, including surface soil texture, sodicity (laboratory tested) and degree of self-mulching (field tested). These parameters assess the soil structure, stability and resilience of the soil.

Hazard 4: Soil Acidification

The soil acidification hazard is assessed using three criteria, being soil buffering capacity, pH and mean annual rainfall. In this assessment, soil buffering capacity was based on soil Great Soil Group; surface soil pH and a regional mean annual rainfall range of greater than 900 mm.

Hazard 5: Salinity

The salinity hazard is determined through a range of data and criteria. The recharge potential for the site was determined based on an average annual rainfall of 1,123 mm, with annual evaporation of 1400 to 1600 mm (BOM, 2015). This would suggest a moderate recharge potential.

Based on the annual rainfall data (1,123 mm) and an average annual evapotranspiration of 800 to 900 mm, a low discharge potential for the site due to a likely balanced rate of water flow.

The Study Area according to the Salt Store Map of NSW, is located in an area of low salt store. However, due the current available scale of this mapping, laboratory tested EC values were used to determine salt store.

Hazard 6: Water Logging

Water logging was determined by the soils drainage characteristics, specifically field sample evidence of mottling, soil texture attributes as well as slope and climate.

Hazard 7: Shallow Soils and Rockiness

The shallow soils and rockiness hazard is determined by an estimated exposure of rocky outcrops and average soil depth.

Hazard 8: Mass Movement

The mass movement hazard is assessed through a combination of three criteria; mean annual rainfall, presence of mass movement and slope class.

4.2 Land and Soil Capability Assessment

As listed in **Table 16** land within the Study Area has been classified into LSC Classes 5, 6 and 7.

Table 16 Land and Soil Capability Assessment

Soil Type		Hazard Criteria								
Site	**ASC Great Group Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**LSC**
1	Magnesic-Natric Brown Kurosol	2	3	4	5	1	5	3	1	**5**
7	Mesotrophic Brown Kurosol	2	3	4	5	1	5	3	1	**5**
9	Magnesic Brown Kurosol	2	3	4	5	1	5	3	1	**5**
M1	Subnatric Brown Sodosol	2	3	4	5	1	6	3	1	**6**
M2	Mesonatric Brown Sodosol	2	3	4	5	1	6	3	1	**6**
M3	Subnatric Brown Sodosol	5	3	4	5	1	5	7	1	**7**
M6	Mesonatric Brown Sodosol	2	3	4	5	1	5	3	1	**5**
M7	Mesonatric Brown Sodosol	2	3	4	5	1	5	3	1	**5**
2	Subnatric Brown Sodosol	2	3	4	5	1	6	3	1	**5**
3	Eutrophic Brown Dermosol	2	3	4	5	1	6	3	1	**6**
6	Mesotrophic Brown Dermosol	2	3	4	5	1	6	3	1	**6**
8	Dystrophic Brown Dermosol	2	3	4	5	1	6	3	1	**6**

Three dominant LSCs present in the Study Area are Classes 5, 6 and 7, comprising 75 hectares, 47 hectares and 50 hectares respectively, as shown in **Figure 6**. The limitations associated with each LSC Class are discussed below and the land area of each LSC Class is shown in **Table 17**.

Table 17 Land and Soil Capability Areas

LSC Class	Agricultural Capability Rating	Hectares	%
5	Moderately Low	75	44
6	Low	47	27
7	Very Low	50	29
	Total	**172**	**100**

LSC Class 5 Land

Class 5 land is represented by a Brown Sodosol with a small area of Brown Kurosol. This classification indicates a moderate to low land capability, with severe limitations to high impact land management uses such as cropping. This land is generally more suitable for grazing with some limitations, or very occasional cultivation for pasture establishment. The limiting factor for LSC Class 5 within the Study Area is slope with sodic subsoil. It covers the major portion of the Study Area (44%).

LSC Class 6 Land

Class 6 land is represented by a Brown Dermosol with a small area of Brown Kurosol. This classification indicates Low capability land with very high limitations for high-impact land uses. Land use restricted to low-impact land uses such as grazing, forestry and nature conservation. Careful management of limitations is required to prevent severe land and environmental degradation, it is considered capable for a limited set of land uses such as grazing, forestry, nature conservation and some horticulture. The limiting factor for LSC Class 6 land within the Study Area is waterlogging. It comprises 27% of the Study Area.

LSC Class 7 Land

Class 7 land is represented by a Brown Sodosol. This classification indicates very low capability land, with extremely severe limitations for most land uses. It is generally unsuitable for any type of cropping or grazing due to its limitations. The limiting factor for 11% of LSC Class 7 within the Study Area is shallow soil, whilst steep slope is the limiting factor for 18% of the Study Area. Overall LSC Class 7 covers 29% of the Study Area.

Within the Study Area, 56% of the land area is considered to have low to very low agricultural capability according to definitions given in *The Land and Soil Capability Assessment Scheme: Second Approximation* (OEH, 2013a), whilst the remainder has a moderately low agricultural capability.

351000
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LEGEND

Study Area (LW22-23)

LSC Class and Limiting Factor

LSC 5 - Sodic and Slope

LSC 6 - Waterlogging

LSC 7 - Shallow Soil and Steep Slope

0 100 200 300 400 m

Scale: 1:10,000
GDA 1994 MGA Zone 56

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Land and Soil Capability

FIGURE 6

5 AGRICULTURAL SUITABILITY

5.1 Agricultural Suitability Methodology

The Agricultural Suitability system was applied to the Study Area in accordance with the DPI guideline *Agricultural Suitability Maps – uses and limitations* (NSW Agricultural & Fisheries 1990). The system consists of five classes providing a ranking of rural lands according to their productivity for a wide range of agricultural activities with the objective of determining the potential for crop growth within certain limits. A description of each Agricultural Suitability Class is provided in **Table 18**

Table 18 Agricultural Suitability Classes

Class	Land Use	Management Options
1	Highly productive land suited to both row and field crops.	Arable land suitable for intensive cultivation where constraints to sustained high levels of agricultural production are minor or absent.
2	Highly productive land suited to both row and field crops.	Arable land suitable for regular cultivation for crops but not suited to continuous cultivation.
3	Moderately productive lands suited to improved pasture and to cropping within a pasture rotation.	Grazing land or land well suited to pasture improvement. It may be cultivated or cropped in rotation with pasture.
4	Marginal lands not suitable for cultivation and with a low to very low productivity for grazing.	Land suitable for grazing but not for cultivation. Agriculture is based on native or improved pastures established using minimum tillage.
5	Marginal lands not suitable for cultivation and with a low to very low productivity for grazing.	Land unsuitable for agriculture or at best suited only to light grazing.

The main soil properties and other landform characteristics considered significant for the land suitability assessment are topsoil texture, topsoil pH, solum depth, external and internal drainage, topsoil stoniness and slope as well as bio-physical factors such as elevation, rainfall and temperature. The overall suitability classification for each specific soil type is determined by the most severe limitation, or a combination of the varying limitations.

Agricultural Suitability has been assessed and classified into Classes 3, 4 and 5 for the Study Area. The limitations associated with each Agricultural Suitability Class are discussed below and the land area of each Class is shown in **Table 19** and **Figure 7**.

Table 19 Agricultural Suitability Class Areas

Agricultural Suitability	Study Area		Agricultural Capability Rating
Class	**Hectares**	**%**	
3	75	44	Moderately Low
4	47	27	Low
5	50	29	Very Low
Total	**172**	**100**	

Class 3 Land

Class 3 land consists of Soil Types 2 and 3. Agricultural activity must be based on improved pastures established using minimum tillage techniques or cropping within a pasture rotation. The productivity potential is moderately low as a result of constraints such as low cation exchange capacity, moderate acidity and sodicity on vegetation growth.

Class 4 Land

Class 4 land consists of Soil Types 1, 2 and 3. This classification indicates the land is suitable for grazing but not cultivation. Agriculture activity must be based on native or improved pastures established using minimum tillage techniques. The productivity potential is low as a result of constraints such as seasonal waterlogging and strong acidity in the topsoil.

Class 5 Land

Class 5 land consists of Soil Type 2. This class of land is best managed by the presence of light green timber due to its highly erodible soils and steep slopes. Partial clearing for grazing can occur, however, significant stands of trees are required to maintain soil cover. This soil type is severely constrained by its terrain, physical and chemical characteristics.

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LEGEND

Study Area (LW22-23)

Agricultural Suitability Classes

Class 3

Class 4

Class 5

0 100 200 300 400 m

Scale: 1:10,000
GDA 1994 MGA Zone 56

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Agricultural Suitability

FIGURE 7

6 DISTURBANCE MANAGEMENT

The primary potential need for disturbance management of soil resources is during and shortly after subsidence remediation. Seedsman Geotechnics (2016) predicts maximum vertical subsidence over LW 22 and LW23 to be 960 millimetres. Given these levels of predicted subsidence, no cracking at the surface is anticipated in either rocks or soils, as has been the case with previous underground mining at Mandalong Mine (Seedsman Geotechnics, 2016).

Umwelt (2016) anticipates approximately 2 hectares of remnant ponding as a result of subsidence. Engineered channel earthworks may be necessary to remediate drainage channels and drain paddocks on properties identified in the *Mandalong Mine LW 22 – LW23 Modification Agricultural Impact Statement* (SLR, 2016) (**Figure 8**).

Should remnant ponding require remediation, soils that are subject to surface disturbance should be managed in order to minimise impact and ensure appropriate rehabilitation of the disturbed areas can be undertaken. The soil resources that are likely to be impacted by subsidence remediation are Kurosols, Sodosols and Dermosols.

Where potential impacts have been identified at the locations shown in **Figure 8**, gypsum will be applied for any remediation earthworks where sodic subsoils (where exchangeable sodium is greater than 5) are exposed. The application of gypsum will minimise the potential for tunnel erosion to occur on disturbed subsoil. The recommended application rates are shown in **Table 20**.

Table 20 Gypsum Application Rates

Exchangeable Sodium (ESP)	Gypsum Rate per Hectare	Gypsum Rate per Square Metre
5 to 10%	2 to 5 tonnes	0.2 to 0.5 kilograms
Greater than 10%	5 tonnes	0.5 kilograms

There are no soil stripping or stockpiling activities anticipated within the Study Area as part of the Project.

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LEGEND

Study Area (LW22-23)

Pre-Mining Ponding

Predicted Subsidence LW22 - 23 Ponding

0 100 200 300 400 m

Scale: 1:10,000
GDA 1994 MGA Zone 56

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Potential Remnant Ponding

FIGURE 8

7 SUMMARY

This *Soil and Land Resource Assessment* has been conducted based on the findings of a field investigation and a desktop review of reference information. The findings of this assessment include:

- Soils types within the Study Area are dominated by texture contrast soils which commonly occur with acid and sodic characteristics. ASC soil types are Brown Kurosols (5%) defined by a strongly acidic nature and Brown Sodosols (72%) defined by subsoil sodicity. The remaining soil type is a Brown Dermosol comprising 23% of the Study Area.

- LSC classes range from Class 5 (moderately low capability land) to Class 7 (very low capability land) with approximately 56% of the Study Area classified as having low to very low agricultural capability.

- Agricultural Suitability ranges from Class 3 (land suitable for occasional but not continual cultivation) to Class 5 (land best managed by the presence of light green timber due to its highly erodible soils and steep slopes), with approximately 44% of the Study Area having moderately low agricultural capability.

- No soil stripping within the Study Area is anticipated as a result of the Project.

Management recommendations based on these findings are presented in this assessment and are a guide to mitigating the negligible soil and land resource impacts associated the proposed Project.

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